

REPORT DOCUMENTATION PAGE

AFRL-SR-AR-TR-04-

0317

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1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE

3. REPORT TYPE AND DATES COVERED

15 AUG 2002 - 14 MAY 2003 FINAL

4. TITLE AND SUBTITLE

(STTR PHASE 1) NANOPHOTONIC INTEGRATED CIRCUITS

5. FUNDING NUMBERS

65502F

STTR/TX

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10. SPONSORING/MONITORING
AGENCY REPORT NUMBER

F49620-02-C-0077

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT

DISTRIBUTION STATEMENT A: Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

Luxtera's Phase I activities have yielded a large number of useful passive nanophotonic devices. The nanophotonic grating coupler and ring resonator are of particular importance. First, an update on the progress with these two components will be given, and then a description of an optimal system for leveraging these two components in the form of a multi-wavelength source will be described.

Luxtera has developed these resonators in two configurations. First as a filter alongside a single waveguide, which provides a notch filtering function to the light passing through the waveguide. The second configuration is where the ring is placed between two waveguides, and on resonance light is dropped from one waveguide to the other. Luxtera proposes to use a variation of this second configuration to provide narrowband feedback to the active medium.

20040625 124

14. SUBJECT TERMS
CIRCUITS

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION
OF REPORT

Unclassified

18. SECURITY CLASSIFICATION
OF THIS PAGE

Unclassified

19. SECURITY CLASSIFICATION
OF ABSTRACT

Unclassified

20. LIMITATION OF ABSTRACT

UL

Standard Form 298 (Rev. 2-89) (EG)
Prescribed by ANSI Std. Z39.18
Designed using Perform Pro, WHS/DIOR, Oct 94



Luxtera, Inc. / Caltech
"Nanophotonic Integrated Circuits"
STTR Fast Track Interim Period SOW
FFT0-0058
Phase 1 Final Report

Principal Investigator: Cary Gunn, VP Technology, Luxtera, Inc.

SUMMARY

Phase I of this Nanophotonics STTR project focused on development of basic passive optical building blocks developed in a high-index contrast material system. Of the many basic components successfully demonstrated, two stand out as particularly useful: grating couplers and high Q ring resonators.

Keeping these two developments in mind, Luxtera proposes a very cost-affordable, nanophotonic source technology that leverages and extends the work from the STTR Phase I. Grating couplers and high Q ring resonators, when used as an external cavity, allow Luxtera to convert a simple VCSEL or Fabry-Perot into a multi-wavelength source or a laser with the high quality typically associated with DFB lasers. Because the wavelength(s) of the resulting laser system is locked to the resonance(s) of the ring resonator, cooling of the active portion of the laser is not required.

Luxtera plans to combine this multi-wavelength source with additional nanophotonic devices to provide a complete DWDM transceiver on a single silicon chip, suitable for high power, low weight, robust and affordable military systems.

DESCRIPTION OF CURRENT STATUS

Luxtera's Phase I activities have yielded a large number of useful passive nanophotonic devices. The nanophotonic grating coupler and ring resonator are of particular importance. First, an update on the progress with these two components will be given, and then a description of an optimal system for leveraging these two components in the form of a multi-wavelength source will be described.

High Efficiency Nanophotonic Grating Couplers

Fiber coupling is a key capability when working with submicron waveguides in silicon on insulator (SOI) film. Luxtera has demonstrated 1.8 dB peak coupling efficiency, and has simulated improved designs that will provide 1.3 dB peak coupling efficiency. Luxtera's nanophotonic grating couplers are also very broadband, a unique feature among grating couplers. For example, our C-band grating coupler only rolls off 0.7 dB at the edges of the band. Furthermore, these designs have proven to be very robust to manufacturing tolerances, and our measured repeatability across a reticle field is exceptional, with one sigma values of 3.6 nm for peak wavelength, and 0.1 dB efficiency.

High Q Nanophotonic Cavities

Luxtera has developed high Q resonant cavities in thin SOI films. Qs as high as 50,000 were observed from cavities with bend radii as low as 2 microns. These cavities have a Finesse of 500, which is state of the art for a resonant cavity in silicon, and results in resonant peaks that are 40 nm spaced, which easily allows for a single resonant frequency within the C-band.

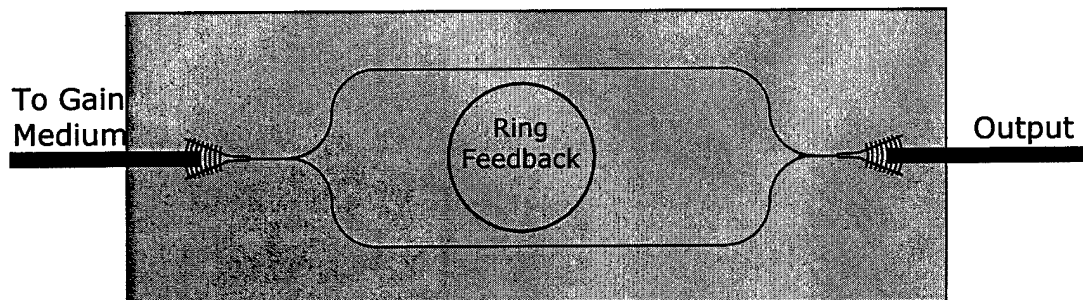
A second type of ring resonator under development has a much smaller free spectral range (FSR), designed to provide feedback at evenly spaced wavelengths, such as the 100GHz spacing used in DWDM systems. The bend radius of this resonator is 140 microns, and Qs as high as 75,000 have been observed, while 40,000 is typical.

Luxtera has developed these resonators in two configurations. First as a filter alongside a single waveguide, which provides a notch filtering function to the light passing through the waveguide. The second configuration is where the ring is placed between two waveguides, and on resonance light is dropped from one waveguide to the other. Luxtera proposes to use a variation of this second configuration to provide narrowband feedback to the active medium.

Luxtera has also examined Erbium implantation into the cladding oxide of our waveguides in order to produce on-chip gain. Initial implant experiments were done at very low implant energies, and sufficient implant depth to attain good modal overlap with resonator modes was not achieved. However, Luxtera will implant Erbium into high Q ring resonators, which can then also be critically coupled to a 1480 nm pump. This work will be done in collaboration with Caltech and the Italian Institute for Microelectronics and Microsystems in Sicily, which has a world-class 1.7MV implanter for Erbium implantation.

DESCRIPTION OF WORK FOR STTR FAST TRACK INTERIM PROJECT

Luxtera proposes to leverage Phase I developments in coupling efficiency and high-Q filtering to construct nanophotonic sources of unprecedented low cost and high performance. A basic schematic of the proposed laser is given below.



Luxtera's technology is uniquely suited for this development because of the following capabilities:

1. Our high Q give us sufficient coherence length to enable design
2. Uses affordable, off the shelf active element
3. Wavelength locking/tuning will be possible due to electrical integration
4. High efficiency grating couplers with optimized mode profiles are possible
5. Integration with CMOS VLSI electronics
6. High volume manufacturing process

Our matching funds have been attained because we have uniquely compelling applications:

1. Low cost Multi-wavelength source
2. Low cost DFB functionality
3. Tunable OR locked wavelength
4. Direct integration with modulation
5. Integration with Luxtera's complete DWDM platform
6. Integration of mode selecting filters

Additional work not proposed below, but which will be proposed in the full Phase II Nanophotonics STTR application involves the design, fabrication and characterization of novel photonic crystal couplers, waveguides, and cavities, which should further reduce the overall size of these integrated nanophotonic systems.

In addition, integration of additional complexity such as tunable passband filters and interleavers will be added to the external cavity in order to perform mode selection.

Statement of Work for Interim Period

1. Advanced Design of Next Generation Components
 - 1.1. Design a grating coupler specifically for coupling light from a VCSEL, which has a substantially different mode profile than a single mode fiber, to which the existing grating couplers are designed
 - 1.2. Design a grating coupler specifically for coupling light from an edge emitting Fabry-Perot laser's unique mode.
 - 1.3. Design external cavity feedback optimized for multi-wavelength source operation, capable of supporting many evenly spaced modes.
 - 1.4. Design external cavity feedback for single frequency source, using a high Finesse cavity to exclude undesired lasing modes.
 - 1.5. Design external cavity for electrical tuning of a laser source by incorporation of a phase modulator within the ring resonator.
 - 1.6. Design two coupled ring resonators for a vernier cavity effect for an electrically tunable laser source.
2. Prototype Fabrication of Next Generation Components
 - 2.1. Using ebeam lithography and etching at Cornell Nanofabrication facility, Luxtera will construct small a small number of promising grating couplers designed as described above. Two grating couplers will be fabricated back to back, so that light can be coupled into the chip, down a waveguide, and back out of the chip, allowing direct measurement of the coupler losses.
 - 2.2. Using the best performing grating couplers from step 2.1, Luxtera will construct passive external feedback cavities to demonstrate proof-of-principle of this type of laser effect. Actively tuned cavities will be pursued in Phase II of this work.
 - 2.3. Erbium will be implanted into a high Q ring resonator in such a manner that a strong overlap with the optical mode is achieved.
3. Characterization of Device Performance
 - 3.1. Luxtera will modify the existing fiber coupling setup to handle both VCSEL and Fabry-Perot Lasers for alignment with grating couplers.
 - 3.2. Luxtera will couple light through grating couplers, and experimentally verify agreement with simulation results and select the best candidates for incorporation with an external cavity.
 - 3.3. Luxtera will couple light through the external cavity, and characterize basic properties of the external cavity optical source, such as side-mode suppression. Advanced techniques required to measure the expected narrow linewidths will be performed during Phase II due to their complexity.
 - 3.4. The Erbium doped ring will be pumped with light that is on resonance with the ring, providing a strong optical pumping effect. The linewidth of the emitted radiation will be measured.